ATOMIC PROCESSES IN PLASMA AND DATABASE OF ATOMIC DATA

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ABSTRACT

Atomic processes in plasmas are reviewed. Databases for atomic numerical data are important to provide data for plasma diagnostics and modeling. We have constructed a database of autoionizing state energy levels and dielectronic satellite lines for plasma diagnostics. The database is available though WWW.

INTRODUCTION

Various kinds of atomic and molecular processes take place in plasmas and understanding these processes is important for diagnostics and investigating plasmas. Spectral lines bring us information on plasmas, such as ionization stages, electron density and temperature, ion density and temperature, radiation loss, or magnetic field strength. Emission lines produced by charge transfer processes between impurity ions and a neutral beam are often used for plasma diagnostics in fusion plasmas. For such diagnostics and plasma modeling atomic and molecular data are necessary and the database system, as a compilation of numerical atomic data and their retrieval system, is important and useful.

There are some numerical databases available through WWW, such as the numerical database of wavelengths and transition probabilities made by NIST [1] and others. NIFS has the retrievable numerical database systems AMDIS for cross sections of ionization, excitation, and recombination by electron impact and CHART for cross sections of ionization and charge transfer by ion-atom collisions [2]. Recently IAEA has established a general search engine GENIE connecting several databases in the web to search for oscillator strength/transition probabilities (6 databases) and electron impact ionization and excitation cross sections (2 databases) [3]. The world around the atomic databases becomes more convenient with this system for users, since it covers the main data categories for users interests. However, there is no available database for inner-shell satellite lines and dielectronic satellite lines, which can be important for plasma diagnostics and modeling.

Here we briefly review atomic processes in plasmas, spectral line intensity, and a new database system for dielectronic satellite lines.

ATOMIC PROCESSES

Various atomic processes govern microscopic plasma conditions. Abundance of ions are determined mainly by balance of electron-impact collisional ionization and radiative, dielectronic, and three-body recombination in laboratory plasmas. Photo-ionization becomes important for some astrophysical plasmas. Ionization and recombination rates depend on electron temperature.

Ions are excited by electron impact collision or by photon absorption and emit spectral lines. Charge transfer processes between ions and neutral beams or neutral atoms in peripheral region of tokamak and stellarator plasmas also make excited ions or atoms and lead to line emission. Radiation of spectral lines, of continuum radiation due to radiative recombination, and of bremsstrahlung causes an energy loss from the plasma.

Spectral line intensities can be calculated by a so-called collisional-radiative model (CRM). The CRM obtains population densities of excited states with assumption that time scales for collisions or radiation are fast enough to be in steady state for excited states. A set of rate equations for excited states is to be solved. Transitions between excited states become more important when the electron density becomes higher, and a coronal model in which a line intensity is determined only by collisional excitation from the ground state is not applicable to most laboratory plasmas. Following is an example of a rate equation for population density n^q_i of excited state i of qth ion (A^{q+}), in which ionization and recombination processes with next ionic-state ion $A^{(q+1)+}$ and recombination due to charge transfer with neutral hydrogen are included.

$$0 = \frac{dn_i^q}{dt} = -n_i^q \sum_{j \neq i} C_{i,j}^q n_e - n_i^q \sum_{j<i} A_{i,j}^q + \sum_{j \neq i} n_j^q C_{j,i}^q n_e + \sum_{j>i} n_j^q A_{j,i}^q \\ - n_i^q S_i^{q,q+1} n_e + n_0^{q+1} \alpha_i^{q+1,q} n_e + n_0^{q+1} n_0^H X_i^H \qquad (1)$$

where $C^q_{i,}$ are collisional excitation/deexcitation rate coefficients, $A^q_{i,j}$ are radiative transition probabilities, $S_i^{q,q+1}$ are collisional ionization rate coefficients from ion qth to (q+1)th, $\alpha_i^{q+1,q}$ are recombination rate coefficients from ion (q+1)th to qth (including radiative, dielectronic, and three-body recombination), and X^H_i are the charge transfer rate coefficients for collision of (q+1)th ion and neutral hydrogen. Spectral line intensity per ion is then obtained as $I^q(i \rightarrow j) = A^q_{i,j} n^q_i$ (photons $s^{-1}cm^{-3}$).

All these atomic data are necessary to solve the equation, but collisional excitation rate coefficients (or cross sections) are often difficult to obtain and also the values may disagree largely between different authors who used different methods to calculate the cross sections [4]. Compilation, comparison, and evaluation of such atomic data are very important.

Inner-shell satellite lines and dielectronic satellite lines are observed in various hot plasmas (e.g. [5,6]). Dielectronic satellite lines are produced during dielectronic recombination (DR) which is an important process in high temperature plasma. DR from H-like ion to He-like ion, for example, is as follows:

$$A^{+q}(1s) + e \rightarrow A^{+q-1}(2pnl) \rightarrow A^{+q-1}(1snl) + h\nu(2pnl \rightarrow 1snl) . \qquad (2)$$

An electron is captured to a doubly excited state 2pnl. Successively radiative transition to 1snl state occurs and the satellite line is emitted (see Fig.1). This line

(2p*nl* → 1s*nl*) is usually observed near the resonance line (2p→1s) of H-like ion in a spectrum. The intensity ratios of the resonance line to the satellite lines are used for electron temperature diagnostics, since the excitation energy for electron capture to a doubly excited state is lower than that of 1s-2p transition and the temperature dependence of two processes is different. Satellite lines observed in solar flares were actually analyzed for electron temperature diagnostics in Refs.[7,8].

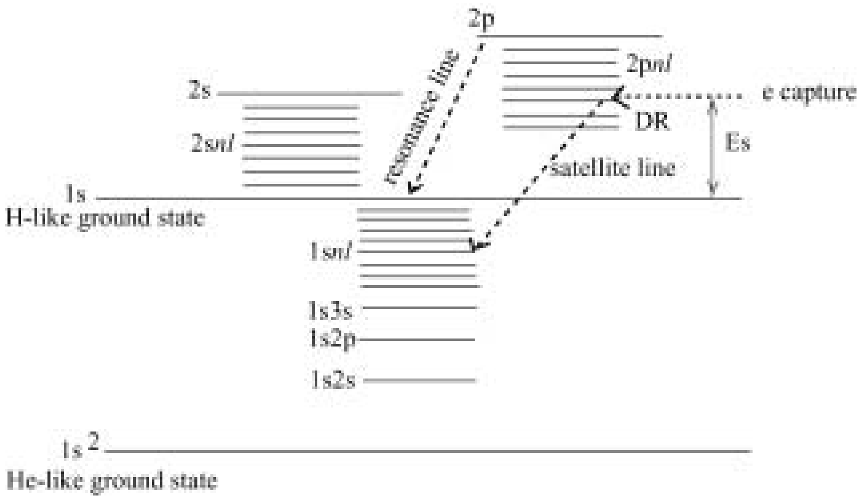

Fig.1 Schematic energy level diagram for H-like and He-like ions. Resonance line (2p → 1s) and satellite line (2p*nl* → 1s*nl*) are shown.

NUMERICAL DATABASES

NIFS and other data centers provide numerical databases on atomic data. A list of available database is found at [9], for example. We recently started to construct a numerical database for dielectronic satellite lines and energy levels of autoionizing states as a collaboration project between Japan and Korea. There was no available database on the physical values, but dielectronic satellite lines are often observed in high temperature plasma, such as fusion plasma [5,6] and solar flare [7,8] and the database will be useful for plasma diagnostics and modeling.

This database contains numerical data of wavelengths and intensity factor Q_d

for satellite lines, and energy levels, autoionizing rate A^a, and sum of transition probabilities $g_i\Sigma_j A^r{}_{i,j}$ for autoionizing states. The database is still under construction, but some data are available at [10] (left panel of Fig. 2). A graphic tool for displaying satellite line spectra is being developed at [11] (right panel of Fig. 2). Line intensity of the satellite line $I(i,j)$ per ion has a relation with the intensity factor $Q_d(i,j)$ as follows:

$$I(i,j) = 3.3\times10^{-24}\left(\frac{I_H}{kT_e}\right)^{3/2}\frac{Q_d(i,j)}{g_0}\exp\left(-\frac{E_i^s}{kT_e}\right) \text{ (photons cm}^3\text{s}^{-1}\text{)}, \qquad (3)$$

where I_H is the ionization potential of hydrogen, T_e is electron temperature, g_0 is the statistical weight of initial parent state i_0 (e.g. 1s for case of eq.(2)), and $E^s{}_i$ is energy level of autoionizing state i measured from initial state i_0 (see Es in Fig.1). Intensity factor $Q_d(i,j)$ from autoionizing state i to final state j is obtained with the statistical weight g_i, autoinization rates A^a, and transition probabilities A^r as follows:

$$Q_d(i,j) = \frac{g_i A^a(i,i'_0)A^r_{i,j}}{\sum_{i'_0} A^a(i,i'_0) + \sum_k A^r_{i,k}}, \qquad (4)$$

where $\Sigma_{i'0}\mathrm{A}^a(i,i'_0)$ is the sum of autoionization rates from i to all possible channels i'_0. For the most cases, $A^a>>A^r$ and $Q_d(i,j) \approx g_i A^r_{i,j}$ approximately. Figure 3 shows an example of data table and spectra for the DR satellite lines. As seen in the right panel of Fig.3, we simply use Q_d for plotting satellite line spectrum now, which gives rough idea for the spectrum. We are developing a graphic tool to plot spectrum with eq.(3) for data which have $E^s{}_i$. Currently data for dielectronic satellite lines are taken from Refs.[12-17] and data for autoionizing states are calculated by U. I. Safronova (private communication) with the MZ code [18] or Cowan's code [19]. Compilation of numerical data and improvement for the graphic tools are in progress and unified database system with numerical data tables and graphics will be available in future at both NIFS and KAERI web sites.

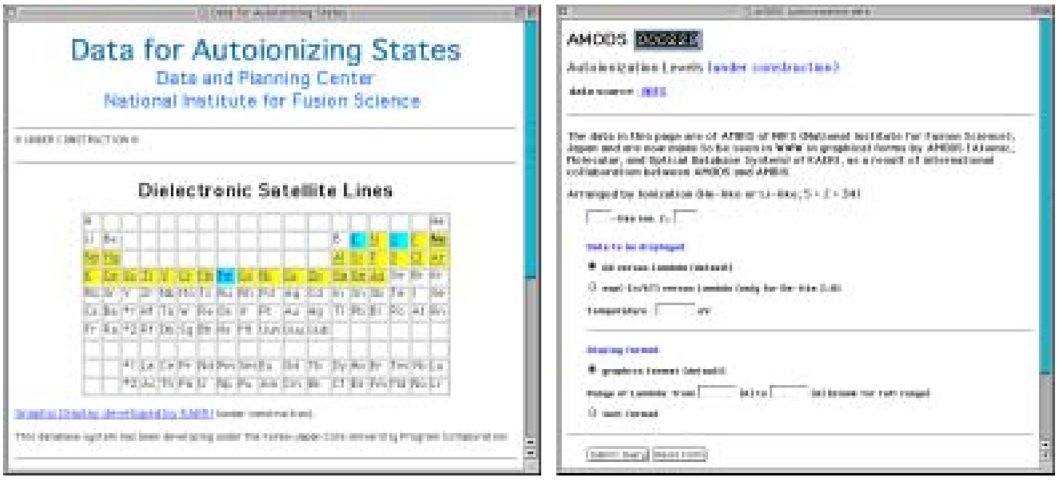

Fig.2 Database homepage image for autoionizing states and satellite lines. Left is for data compilation page at NIFS [10] and right is for graphics of satellite line spectra at KAERI [11].

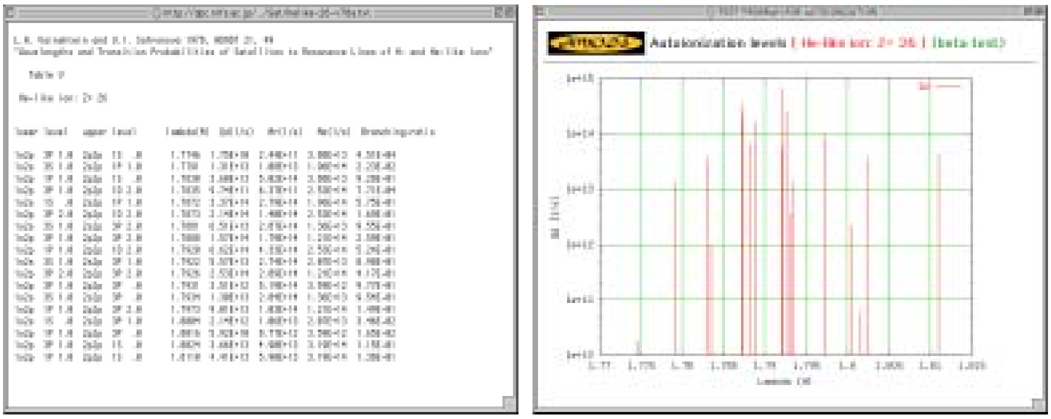

Fig.3 An example of numerical data table of DR satellite lines for He-like Fe ion at [10] (left) and DR satellite spectra (Q_d vs. wavelength) at [11] (right).

CONCLUDING REMARKS

Making databases and providing numerical atomic data to users for plasma diagnostics and modeling are important but not easy work because of time consumption and man power. The work is supported by international collaboration with many atomic physicists.

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